The construction of a multi CCD camera

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Sky surveillance projects require the largest possible sky coverage. Doing so with a given image sampling (number of arc seconds per pixels) and a given telescope require the largest possible detector. There are three ways of installing large CCD detectors at the focus of a telescope: 1-use a single intrinsically large detector; 2-build a large CCD matrix using buttable devices; 3-build a multi CCD camera, provided the field of view of the telescope is large enough.

This report documents work efforts on the last solution.

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Introduction :
Sky surveillance projects require the largest possible sky coverage. Doing so with a given image sampling (number of arc seconds per pixels) and a given telescope require the largest possible detector.

There are three ways of installing large CCD detectors at the focus of a telescope :
1- Use a single intrinsically large detector
2- Build a large CCD matrix using buttable devices
3- Build a multi CCD camera, provided the field of view of the telescope is large enough.

The largest CCD available as of this writing are Philips CCDs, which are 86x110mm large. They offer a 7168x 9216 pixels area of 12 microns each, covering more than 1.5x2 degrees on the sky at our telescope (and an image size of 132 megabytes in memory). Philips is now producing these devices on 6 inch wafers, and intends to produce even larger devices using 8 inch wafers in the next future. While these devices are not as efficient as other thick devices due to the fabrication process, they do represent a very interesting technical solution, since the installation of such a device inside our telescope should be relatively straightforward. Moreover, large single devices require only a single controller, and the detector's alignment in the focal plane is trivial using the telescope's focussing system. The limit with this technology is the fact that the controller has to be very fast in order to allow relatively short readout times. It would take around 7 minutes to red such a CCD with our current controller in full resolution mode. Another interesting device is Loral's CCD 485, which has 4096x4096 pixels. Its low price of $15,000 and large size (62x62 mm, 32 megabytes per image) makes it a very interesting choice.

Cameras using buttable devices have been built in many sizes, the most familiar ones being 4Kx4K using 2Kx2K two side buttable devices or 8Kx8K, using 8 2Kx4K three side buttable devices. Such a large detector will have a physical size of 124x124mm, and a memory size of 128 megabytes per image. The alignement procedure of such large chips is still very complex, and the equipment required to perform this alignement is costly compared to the size of a small telescope and observatory such as ours. EEV intends to sell 2Kx6K buttable devices, which would in principle allow the conception of 18Kx12K cameras using 18 such devices, with physical sizes of 184x276mm and memory sizes of more than 450 megabytes per images. Several manufacturers are also working on 4 side buttable devices which would allow cameras only limited by the telescope physical field of view and by their conceptor's imagination and financial capacities. Several such cameras are nevertheless in pojects in the astronomical community, and they are often referred to as « megacams ».
With an estimated price of $100,000 for a thinned 2Kx6K device, more than 1.8 M$ would be require to build a 18Kx12K camera for the detectors alone. This is in the order of 50 years of operating budget for such a small facility as ours. The drawbacks of this technology is that there is a gap between each CCD, allowing moving sources to eventually « slip through » the detector, and that, as in the previous solution it is not possible to use a small correcting lenses in front of each CCDs when using a Schmidt telescope. Another aspect is that the current 8Kx8K cameras (such as made at the University of Hawaii and at Kitt Peak National Observatory) are truly monsters which occupies more than a cubic meter of physical size at the back of a very large telescope, weighing several hundreds of kilograms.
It is to be noted that it is also possible to build such a large camera by « glueing » the silicon devices on a single silicon wafer, but while this solution has advantages as far as flatness and

alignement of the individual CCDs, replacing a device in such a detector is a very complex operation, which while easy for a microelectronics laboratory, is difficult for the average observatory.

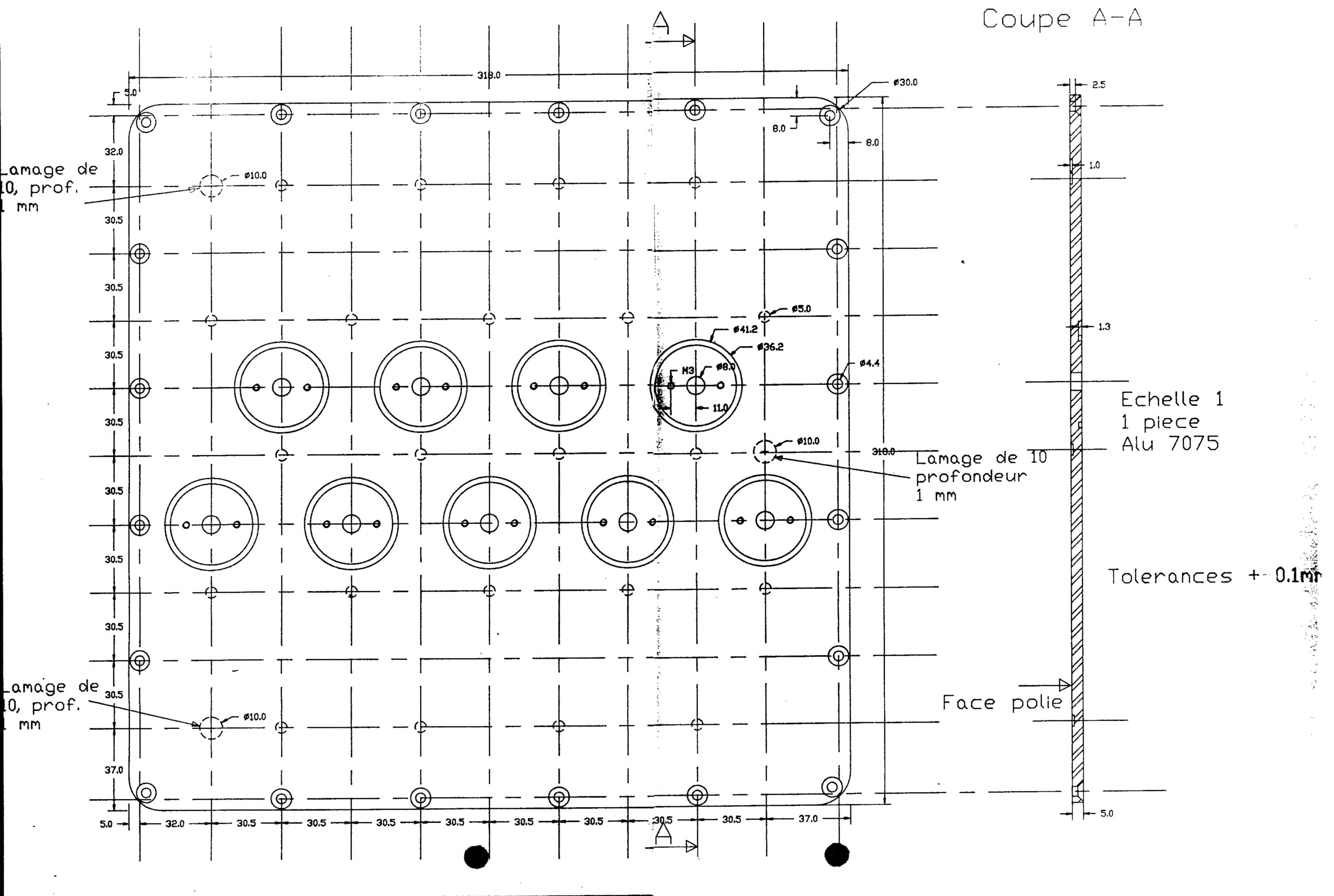
The final solution is the one on which we have worked for the last two years, i.e. placing several individual CCDs in a large focal plane in order to recreate a single continuous image using multiple exposures has also been tried by several other groups, most notably for the Sloan Digital Sky Survey project which uses 30 2K devices in great circle scanning. With the SDSS camera, 2 exposures are required to produce a continuous image of the sky. In our case, taking into account the specificity of our telescope (a 30x30cm curved field of view), we thought that using 9 2K CCDs to create an pseudo array 5 degrees high would be the most cost effective solution available to us. The general arrangment of this array has been described elsewhere (The OCA CCD controller). The devlopment of the multi CCD controller took more time than expected, as did the devlopment of the required detection software. When a first system started to work, then regular observations with this system started to take a substantial part of our available time... Nevertheless between the time this contract was awarded and today, several projects were undertaken in order to foresee the construction of such a multi CCD camera. While it is more than likely that we are going to replace our current 2K device by a larger 4K device or a 7Kx9K one, we think the technology devlopment we did around this idea was a very valuable one. It is to be noted that a single 7Kx9K device covers almost the area of 10 2K CCDs, and both its installation and use at the telescope is easier than using 9 individual chips.
Our efforts have led us to:
- Design a flat liquid nitrogen dewar which would be able to store liquid nitrogen in our focal plane and support 9 2K CCDs.
- Design a very compact alignment system for the above enclosure, able to fit in the available space. This system allow precise positioning in height, translation and rotation of the device. This system would fit either a Peltier or liquid nitrogen cooled system.
- Design and build a peltier cooled mechanical enclosure for a 2K CCD, with an external size smaller than 6x6 cm.

Design of a flat liquid nitrogen dewar

While the use of liquid nitrogen in regular telescopes is a straightforward solution, doing so inside a Schmidt telescope is not very easy since the focal plane has been built for plate holders which are usually less than 10 centimeters thick (4 ''). Ours are 8 centimeters thick only, and we have no back room in order to install a very large camera. So far, we have used Peltier cooled cameras, but the installation of several large CCDs is a problem since the camera is in the optical path and has to reach a thermal equilibrium with the air inside the tube, i.e. generate no heat or cold that would affect the image quality. While a single 2K device requires about 3 watts of heat in order to be cooled 40 C degrees lower than ambient, the required Peltier device generates up to 60 Watts of power. A 9 camera system would require the evacuation of more than 500 watts of thermal power from the inside of the telescope. Another problem is that if we start using the camera with long exposure times, then thermal signal (and therefore induced thermal noise) starts to be a problem. Liquid nitrogen cooled system reach easily -100 degrees of temperature and can be used for very long exposures without any problems. Getting liquid nitrogen inside the telecope's focal plane is a problem, and maintaining all the chips at the same constant temperature can be tricky. The solution to carry nitrogen inside the telescope is to use double wall insulated systems (the parts in which nitrogen circulate are enclosed in vaccuum in another container). Another problem is that it is necessary to store some amount of liquid nitrogen near the CCD in order to give some thermal inertia to the system. In this design, we chose to store about one liter maximum of liquid nitrogen in the back of the CCD modules. A larger (50 liters) dewar would be placed alongside and outside the telescope's tube.This implies a container able to store one liter of liquid nitrogen, flat in shape (no other choice for us), which would supply cold to each of the CCD modules, while allowing some amount of flexibility so as to be able to adjust them individually. Moreover, this container would be enclosed in another container, which would isolate the cold parts in vaccuum, while not collapsing under pressure. Our design is shown in the following plans. It is made of 5 main aluminium parts which are assembled in a liquid nitrogen container and an vacuum resisting container enclosing the dewar. A thin radiation shield should be installed between the walls of these two parts :

- A liquid nitrogen container, made of a container and its cover. In order not to collapse, the container has regularly spaced fingers which are in contact with the cover. These two parts hold together by screws holding a teflon flat gasket for tightness. The shape of this gasket takes into account the complex shape of this part and is cut out from thin teflon sheet.
- A larger vaccuum tight container which contains the above mentioned parts. It is made of two lids and a spacer. The top lid has recesses in which the CCD enclosures do fit. Fingers do also go through this container (and through holes made in the liquid nitrogen container), so as to prevent collapse of the enclosure because of the vaccuum pressure. Cold is brought out from the liquid nitrogen container through the enclosure via red copper « springs » which allow for some flexibility in the adjustment of the CCD enclosures.

Detailed plans are in the following pages.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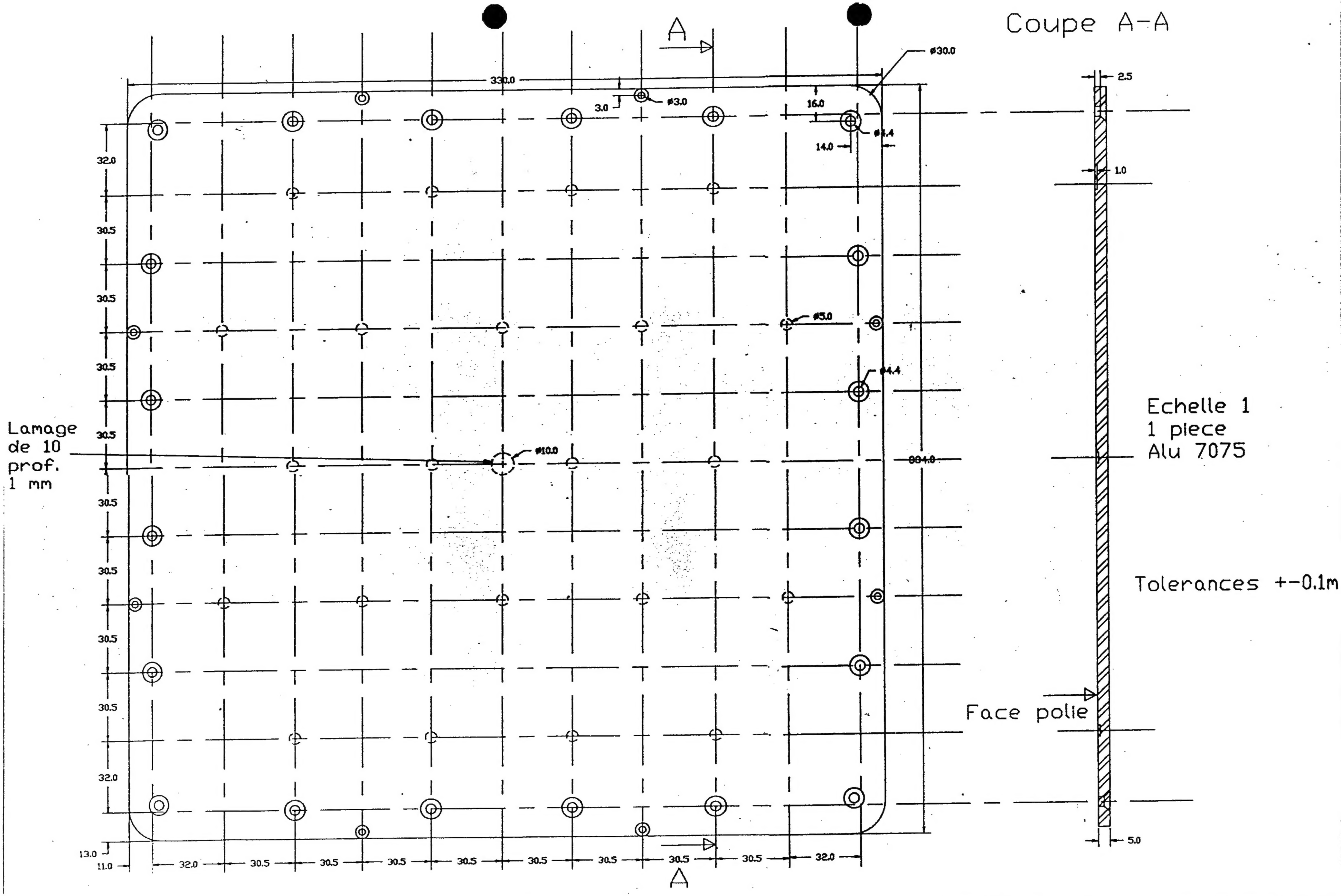

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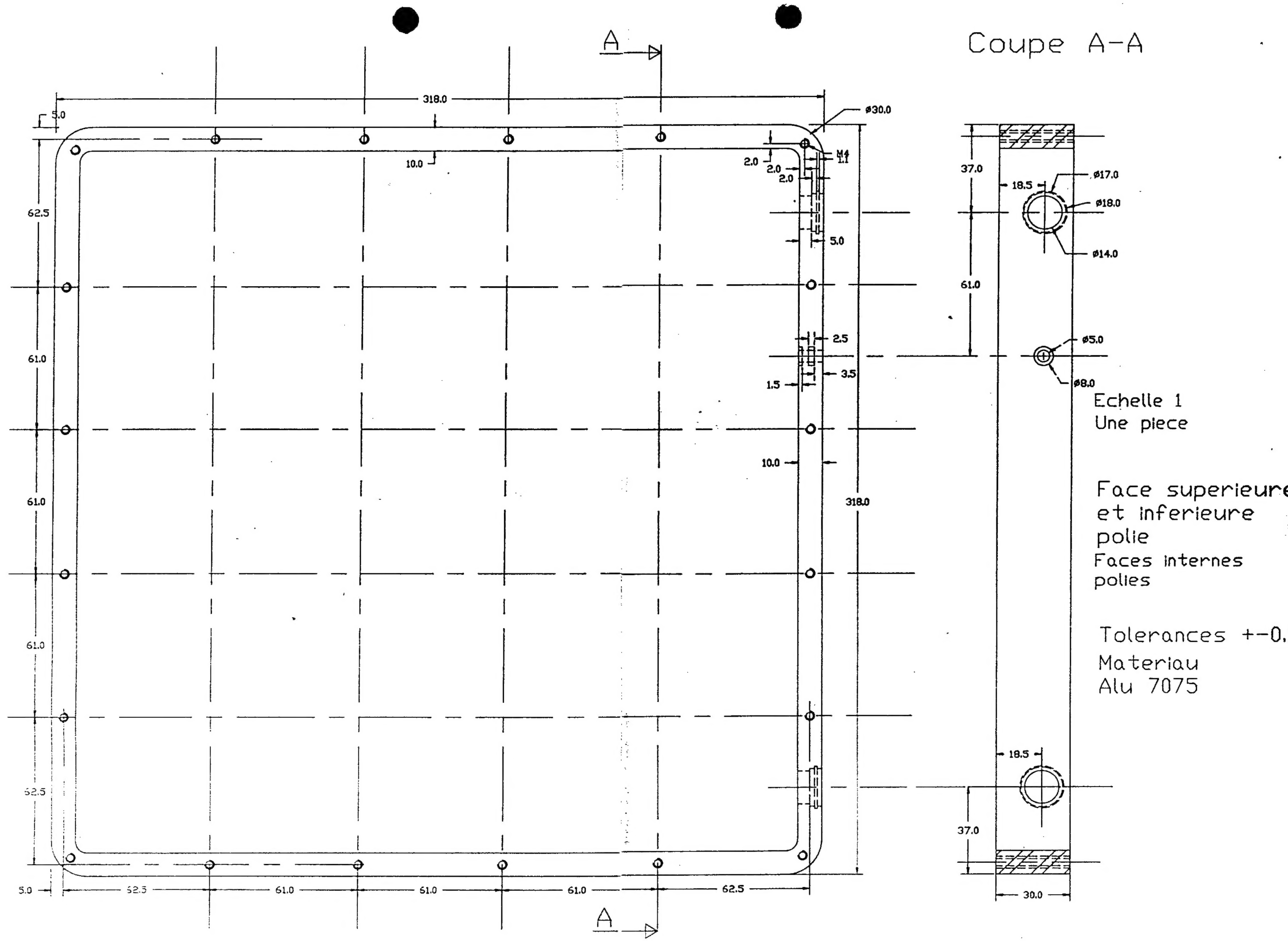

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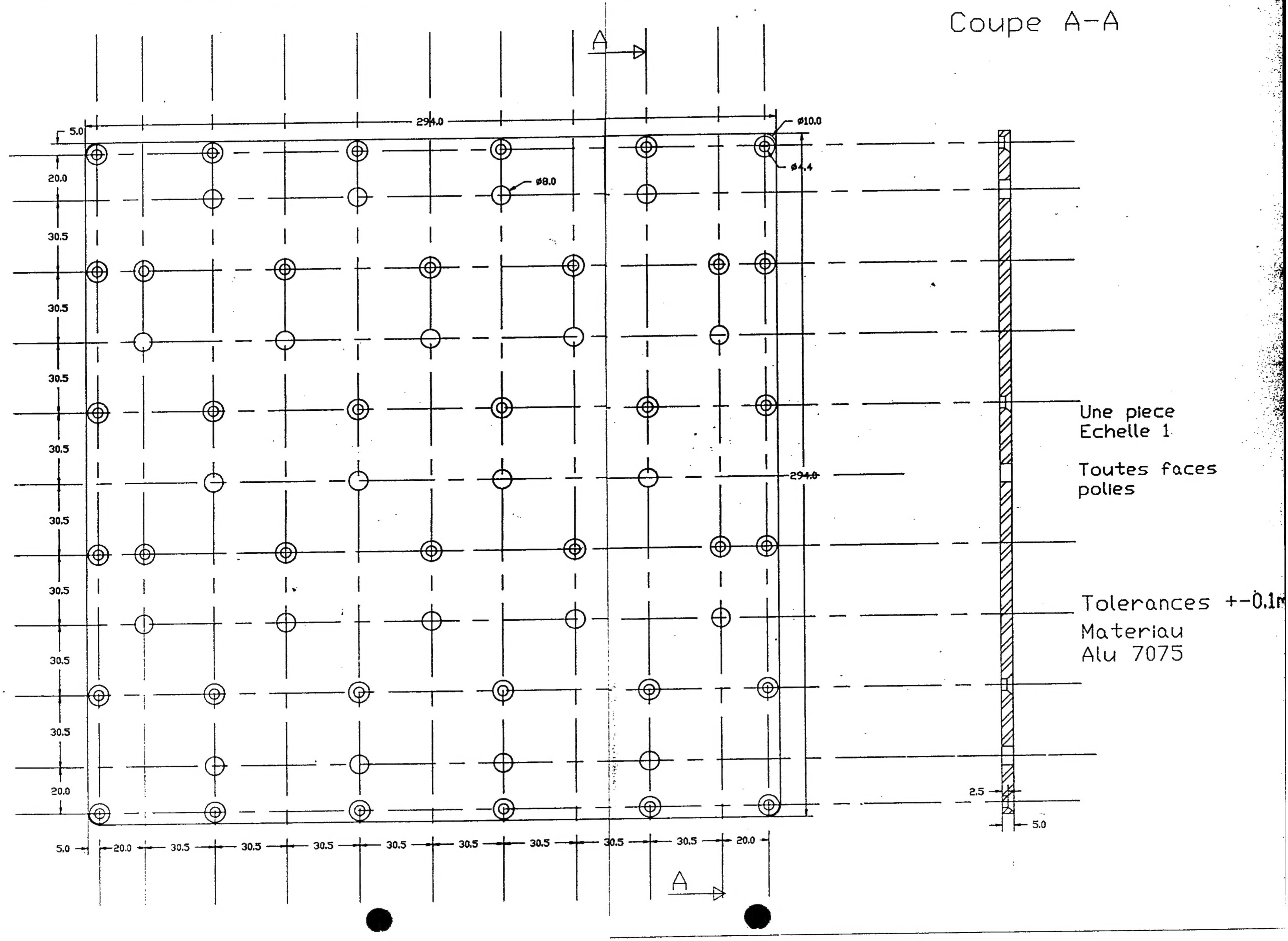
Alu 7075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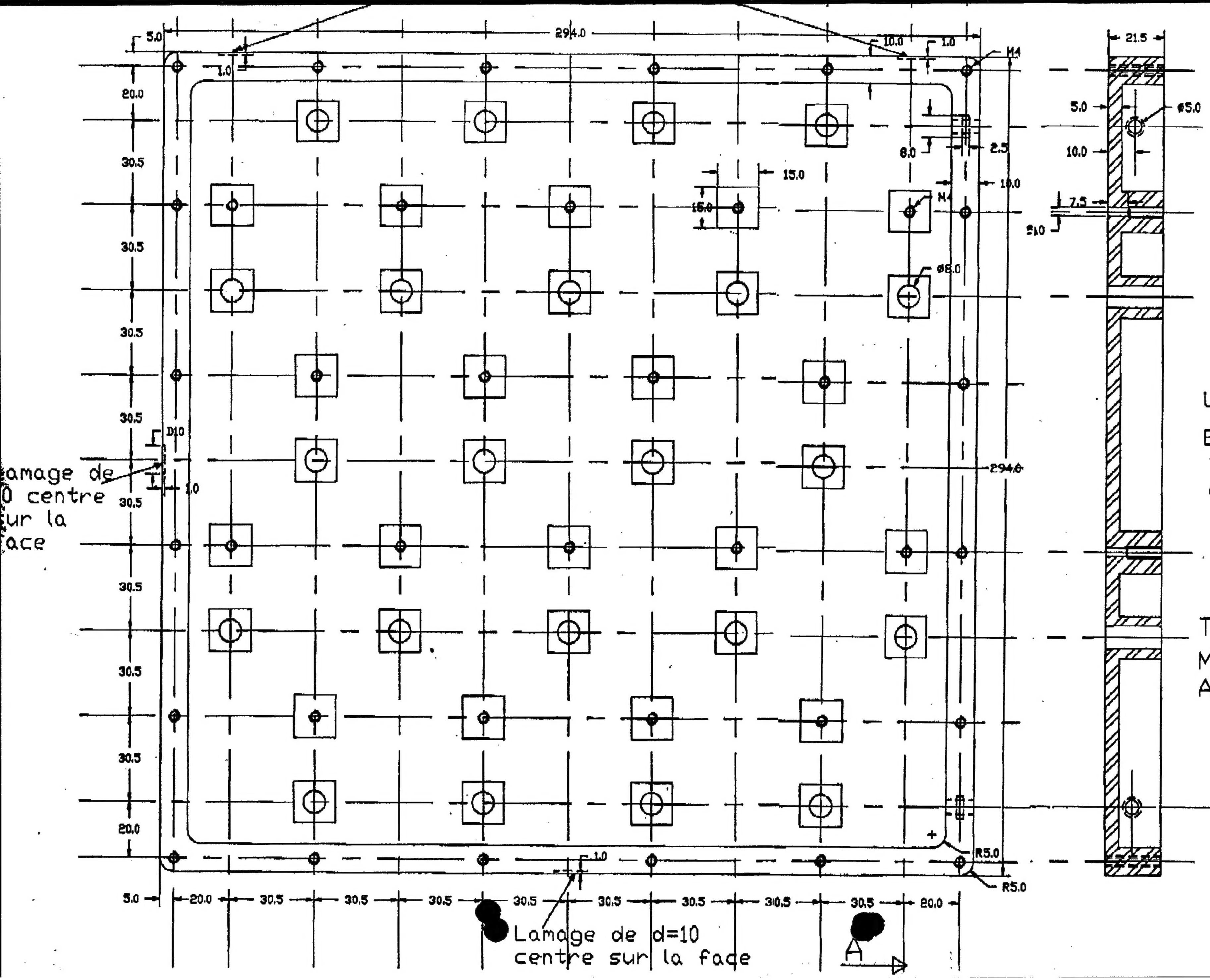


Une piece

Echelle 1

Toutes faces externes poli

Tolerances

Materiau

Alu 7075

Adjustable alignement system for a CCD enclosure

Each CCD has a sensitive surface of 30.72 mm. In our design, each CCD is separated from the next by an amount slightly smaller than 30.72 mm in X and Y. A CCD package is 44 mm wide, leaving less than 8.5 mm around each CCD to install a package, which has to maintain the CCD in the cold and vaccuum, while allowing a correct alignement of the chip in the focal plane, which in our case is curved, with a radius of curvature of 3140mm. The alignement system must provide an alignement in :

- height (Z axis) : Focus the CCD.
- translation (X and Y) : align the CCD so that the overlap between CCD is more or less constant.
- tilt (beta and gamma) : In order to have a flat focus over the CCD surface.
- rotation (alpha) : align the CCD so that its line are parallel with the north direction of the sky.

We designed a 6 points system with a triplet of differential screws and a triplet of excentric screws. Differential screws are screws tapered with a different number of thread per mm. If a screw has a 1 thread per mm, and 1.25mm at its other end, rotating it in two tapared parts will produce a shift of the two parts of the difference between the two threads, in this case 0.2 mm per turn of the differential screw. The excentric screw is mounted in two mechanical parts which rotates as the excentric is turned. As shown in the following pages (comments are written in french...) the alignment can be done since the CCD enclosure is connected to the « vaccuum » container through a large 5mm thick Viton O ring, which has enough play in all directions to allow the alignment with an amplitude of 1 mm.

The way the system works is the following:

Labeling the triplet of differential screws as on the mechanical drawing 1, 3 and 5, and the triplet of excentric screws 2, 4 and 6, we get:

2-4-6 : produces an horizontal shift of the enclosure

1-3-5 : produces a vertical shift of the enclosure

1+3+5 : turning the triplet of differential screws (0.2 mm per turn) in the same direction changes the height of the CCD enclosure (Z direction, i.e. focus)

1+3-5 : produces a rotation along the beta direction (tilt)

1-3 : rotation in gamma

2 : Shift in Y

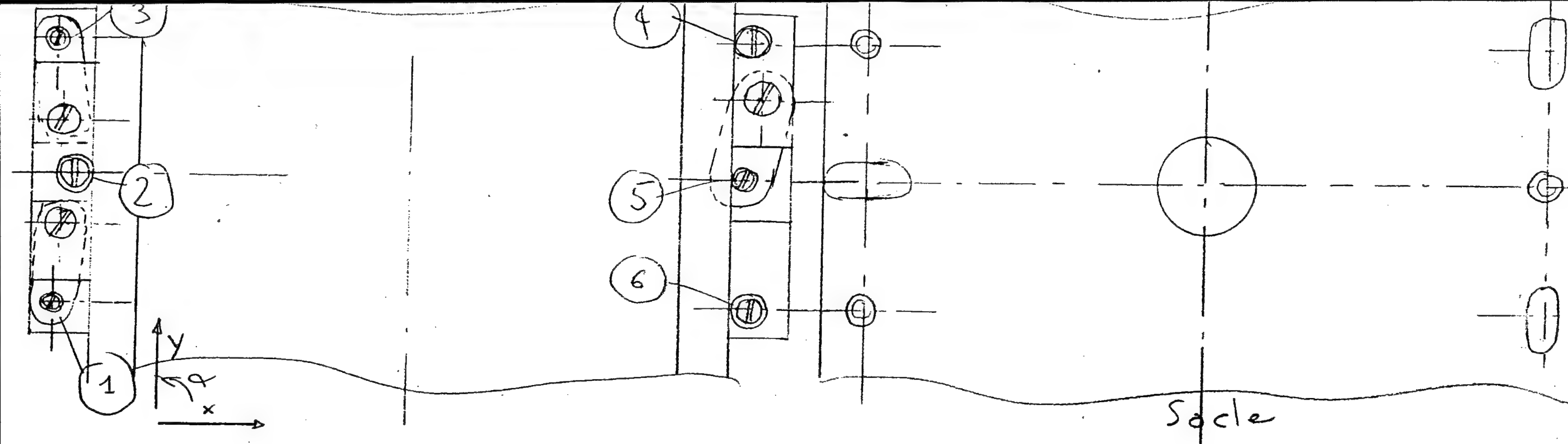
4+6 : Shift in X

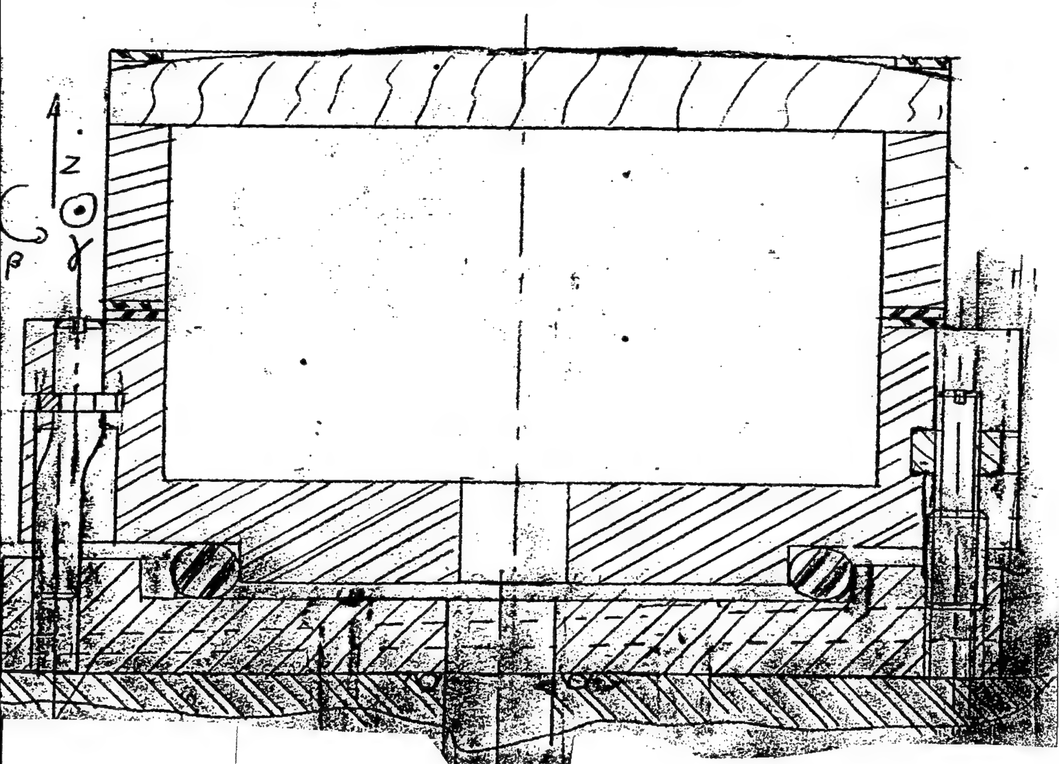
4-6 : Rotation in alpha around 2

Suggested alignment procedure :

We looked carefully into this issue of CCD alignement and believe we can adjust the CCDs in the lab very carefully. We have an old PDS machine and intend to modify its XY stage (precision one micron) in order to adjust the CCD positions. The next stage will be to perform sky tests which can provide direct information on the focus, alignement and tilt of the detector as well as obtaining information on the relative shift between each CCD.

The focus test is part of a routine which we have developed in order to measure the point spread function (psf) of star images at the center and at the edges of the field. This gives us information on focus (several frames are taken while changing the positioning of the CCD through the focussing screws of the telescope, and later examination of stars across the field gives us information on the tilt. Long unguided exposures gives us star trails on which we can verify the rotation of the CCD in respect ot the star drift. We have also developed a procedure to perform this type of alignement using our current camera. Astrometry using the Guide Star Catalog can be used to measure the offset between each field and decide whether or not we need to change this offset. The value of this offset is non critical, provided there is an 20 pixels or so overlap between each field.

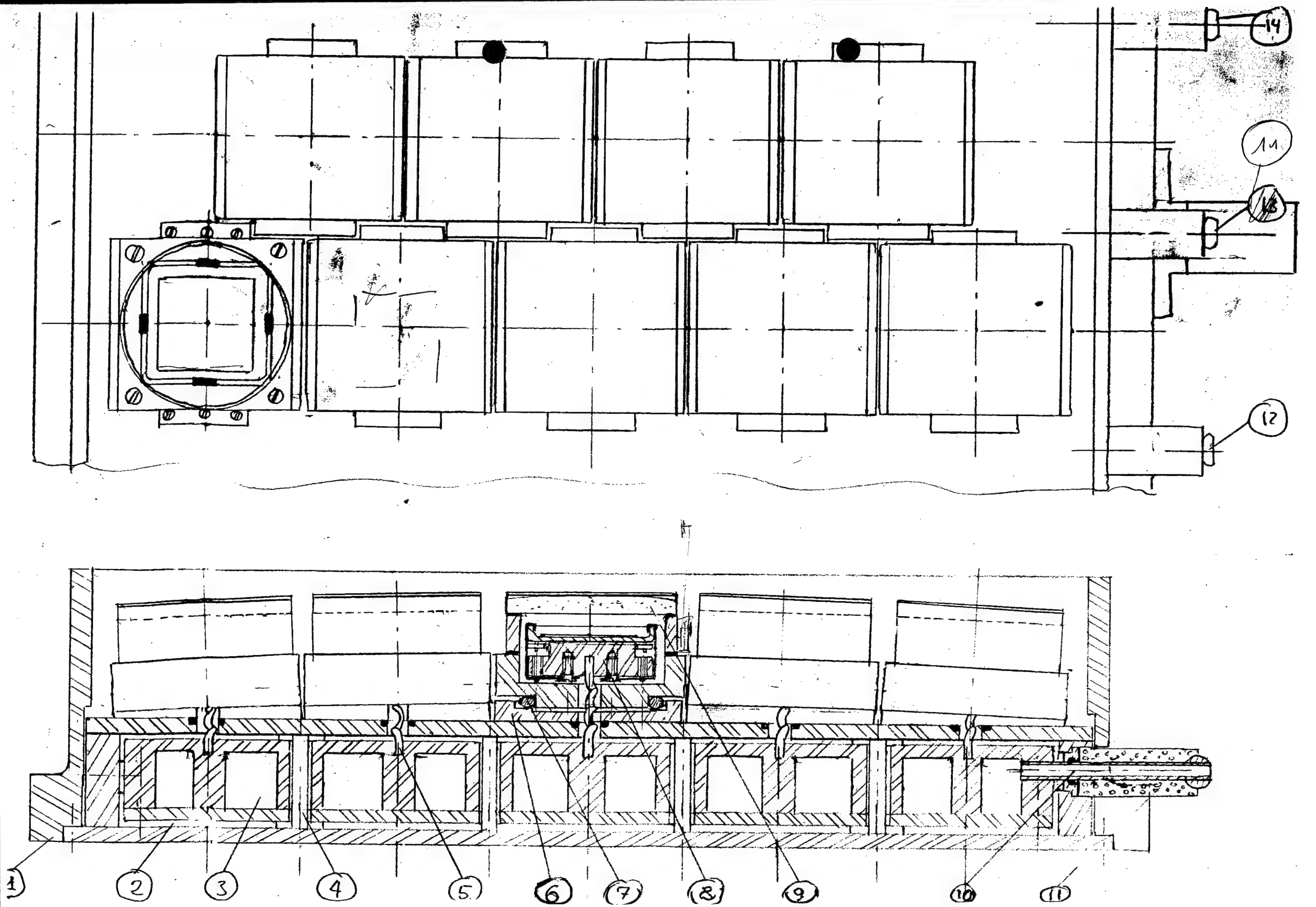




2 - 4 - 6 ⇒ décalage horizontal → excentrique
1 - 3 - 5 ⇒ décalage vertical → filetage différent 0,2mm par tour

1 + 3 + 5 ⇒ déplact en z
1 + 3 - 5 ⇒ rotation en β
1 - 3 ⇒ rotation en γ
2 ⇒ déplact en y
4 + 6 ⇒ déplact en x
4 - 6 ⇒ rotation en α

Dans toutes les directions : mobilité = ± 1 mm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Compact mechanical enclosure

Creating a mechanical system which would just fit the CCD and allow it to work under normal conditions meant several functions had to be realised in a very tight space. We built a functioning peltier cooled enclosure in order to demonstrate the feasability of running a 44mm package in 60 mm space :

- Cooling the device : Install a dual stage peltier cooler, a heat exchanger at its back, and provide two small pipes for glycol cooling.
- Provide vaccuum, so that the CCD does not freeze while cold.
- Provide a front lens. In order to gain space, we used an special epoxy in order to glue the lens in place instead of using an O ring system. This epoxy (Stycast 2850) is made so as not to outgas in vaccuum.
- Provide a way to connect the CCD to the external world. Even the smallest connectors were too large for our design. We are running the different wires (to the CCD, to the PT100 proble, to the Peltier cooler) through a separation between the bottom and the top of the enclosure. We tested both a dual teflon gasket which worked with small wires (i.e. all wires but the peltier wires), and a system using the same epoxy as used to hold the lens in place. The teflon gasket would be appropriate for a liquid nitrogen cooled system. The gaskets are cut from thin teflon sheet to the desired shape. For the Peltier cooler, we glued hermetically everything in place, which would cause problems if we had to dismount the unit. Still it was the only practical solution found. We include a report written by two students who worked on this design. Once the wires are outside the enclosure, they are brought to a small flat connector with a 0.1'' pin interval which can then connect to the CCD controller. The available plans were reduced to fit on an A4 format paper, and 2 pictures of the mechanical prototypes are also available.

ANNEXE 2

Calcul du débit de la pompe:

Les essais préliminaires sur le prototype glycol/Peltier ont fait apparaître la nécessité d'absorber 3Watts au capteur.

Or, l'énergie absorbée par de l'azote passant de la température T1 en phase liquide à la température T2 en phase gazeuse est :

$$Q = m\, q_l + m\, C_p\, \Delta T \ [J]$$

$$\Delta T = T2 - T1$$

avec : q_l : chaleur latente massique

C_p : coefficient de chaleur spécifique à pression constante

m : masse d'azote ayant subie l'opération thermodynamique

Puisque que l'on veut absorber 3 J/s au capteur, il faut donc que Q=3J, 'm' étant alors la masse d'azote qu'il faudra pomper par seconde.

$$m = Q / (q_l + C_p\, \Delta T) \qquad [Kg/s]$$

L'azote étant pompé en sortie de l'enceinte, il est pompé en phase gazeuse. 'W' représente alors le débit:

$$W = m / \rho_g \qquad [m^3/s]$$

avec : ρ_g : masse volumique de l'azote gazeux

Le débit de la pompe devra donc être :

$$W = Q / [\rho_g *(q_l + C_p \Delta T)] [m^3/s]$$

$$W = 1000 * 60 * Q / [\rho_g *(q_l + C_p \Delta T)] \text{ [litres/min]}$$

A.N.: $W = 1000 * 60 * 3 / [1.12*(198400+0.25*4.184*1000*100)]$

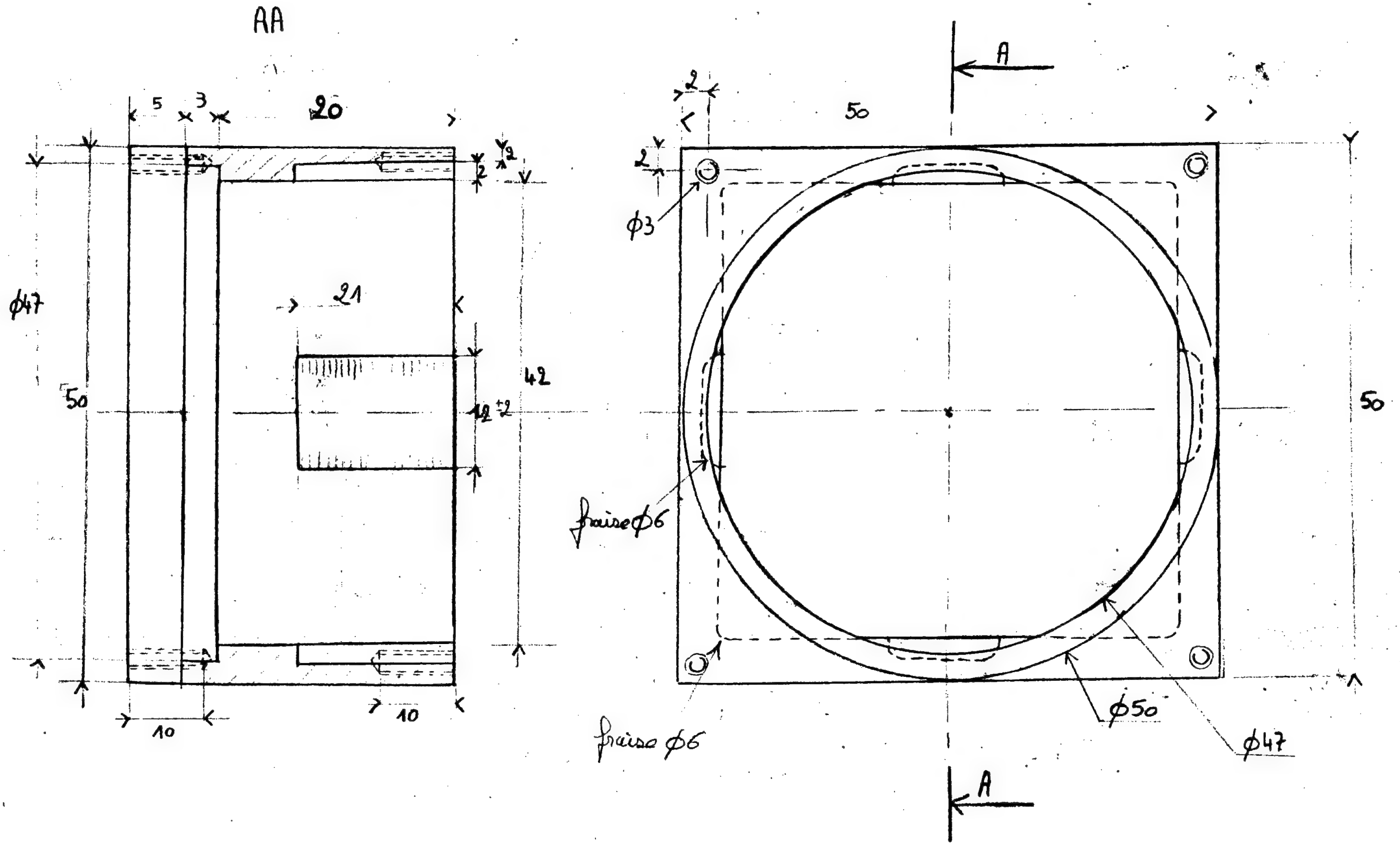
$W = 0.53$ [l/min]

Rq : Deux débits d'azote doivent être distingués:

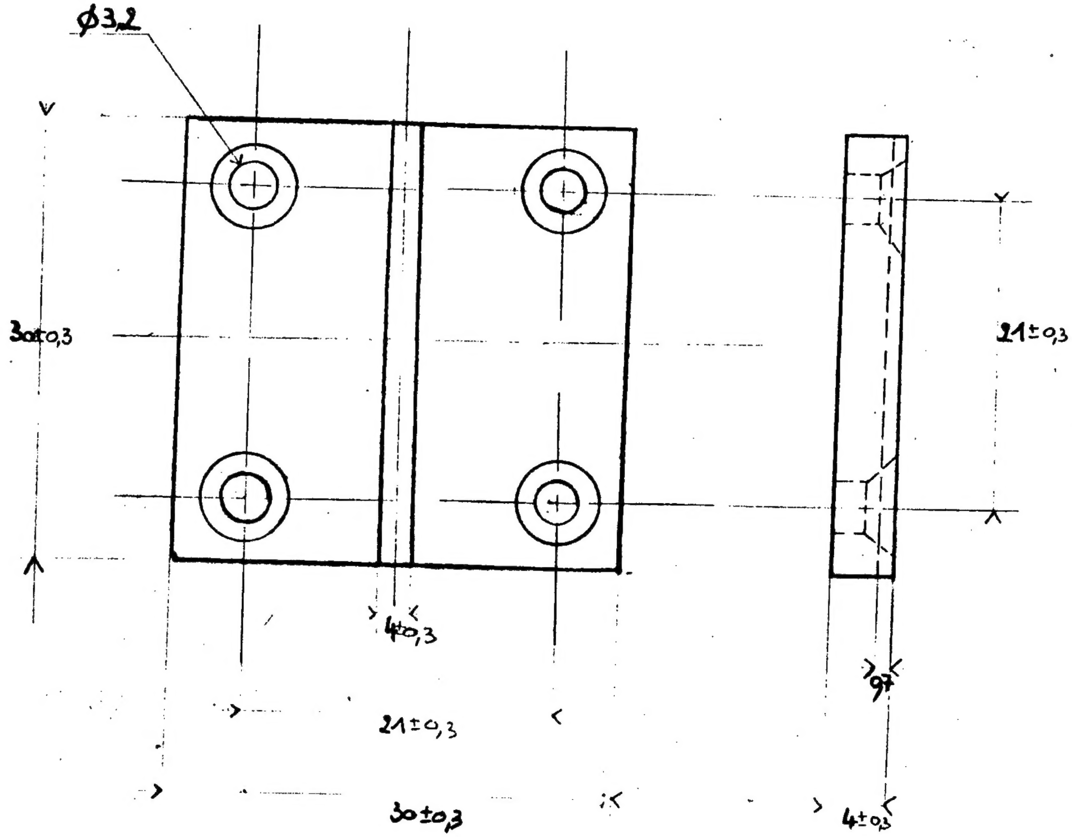
-un débit transitoire (lors de la mise en fonctionnement); le capteur est alors à la température ambiante (≈30°C) d'où ΔT très grand.

-un débit stationnaire où le capteur est à sa température de fonctionnement (≈-100°C). Ce débit stationnaire prend en compte un ΔT inférieur donc l'azote se réchauffe moins et absorbe moins de chaleur. Il en résulte qu'il suffit de prendre en compte le régime stationnaire (ΔT=100°C) qui impose un débit supérieur.

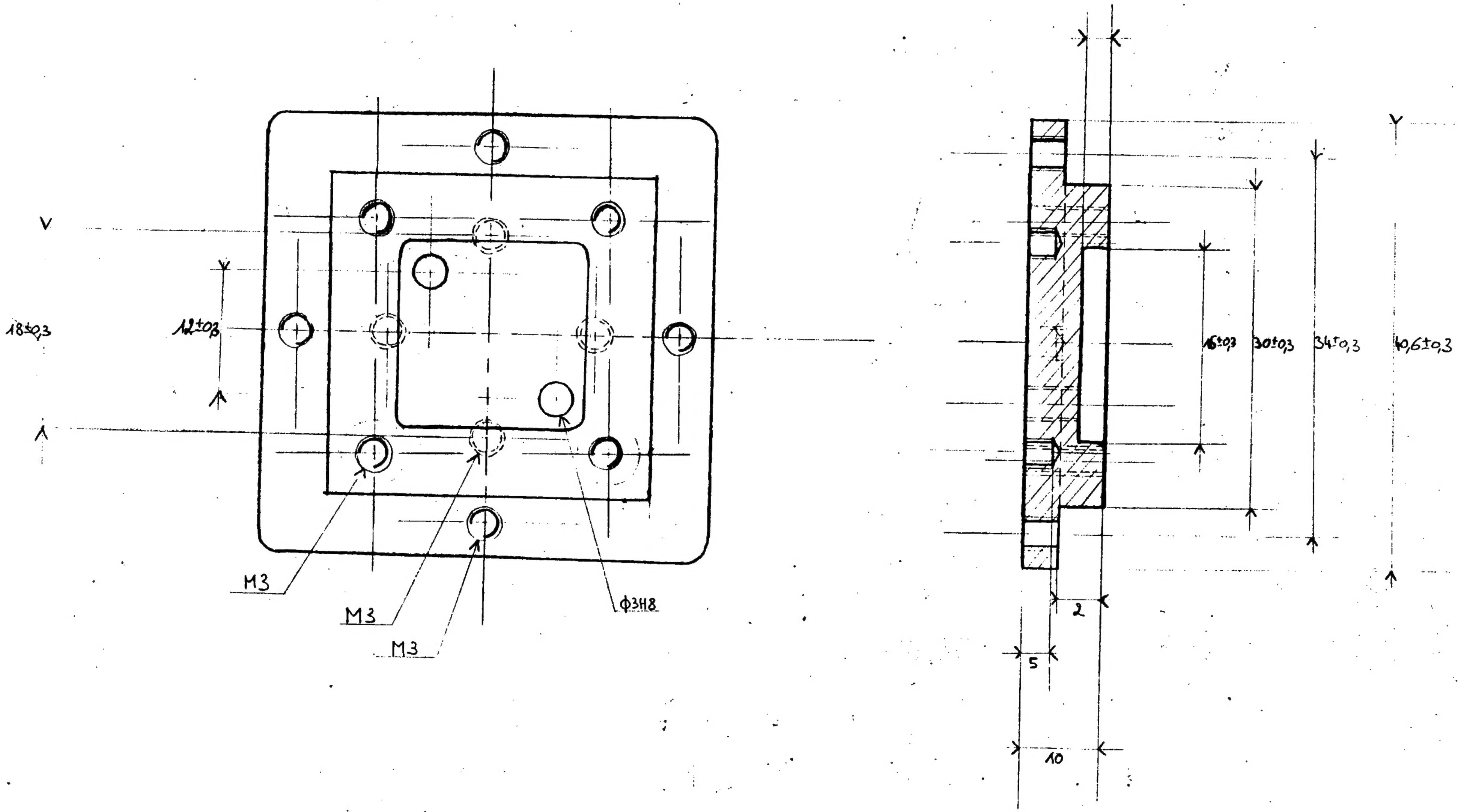
Dessin 1 : Partie avant

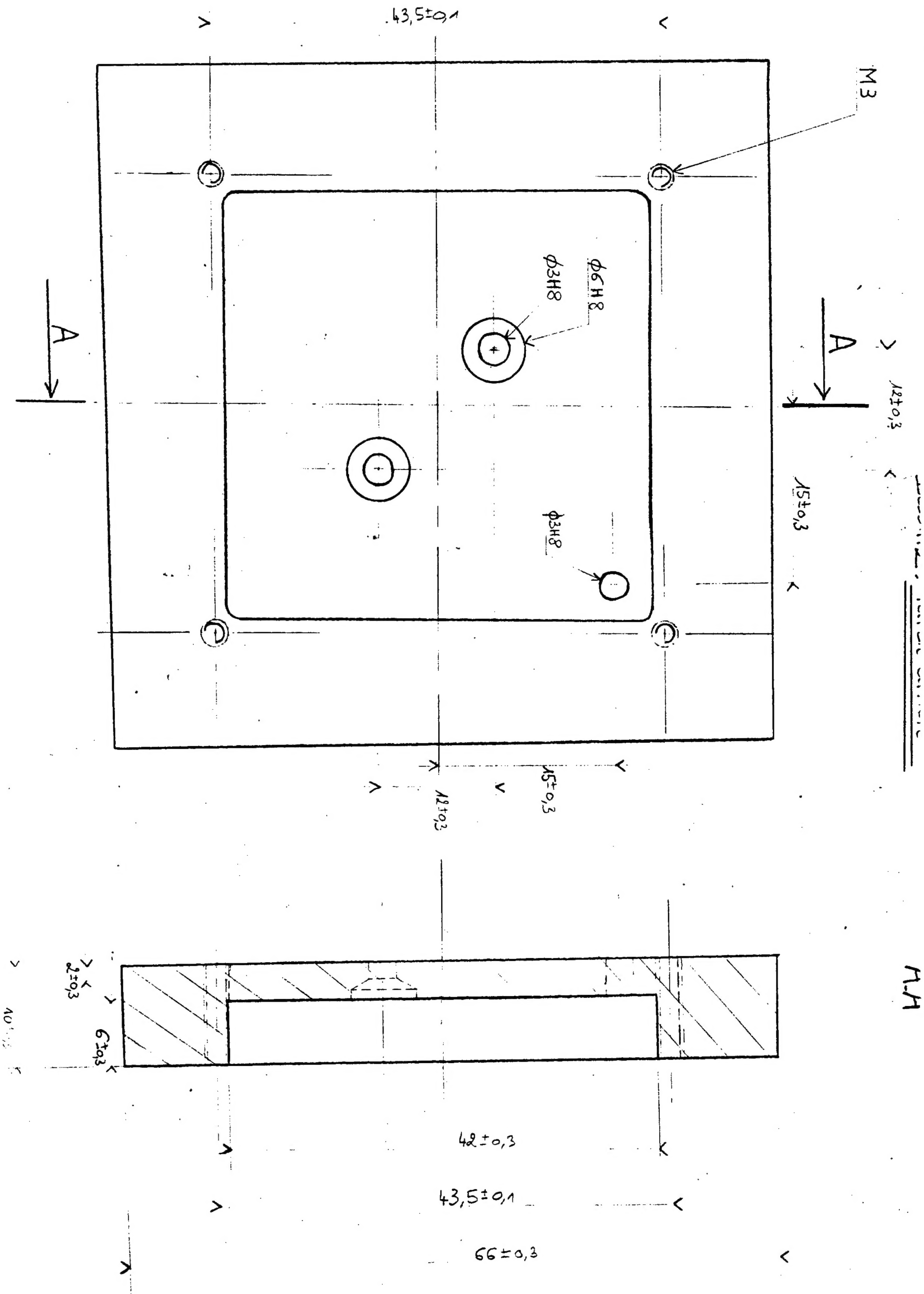


Dessin 4 : Plaque alu appuyant sur capteur CCD :   4



Dessin 3: Chambre de détente du gaz





43,5±0,1
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ϕ6H8
ϕ3H8
ϕ3H8
A
A
12±0,3
15±0,3
12±0,2
15±0,3
A-A
2±0,3
6±0,3
42±0,3
43,5±0,1
66±0,3

Conclusion :

While not easy, it is possible to build a very compact CCD camera. Installing it inside the telescope, while not an easy operation is feasible. In fact, even 27 CCDs could theoritically be installed inside the focal plane. However, larger CCDs provide more room, much less connections. In 1997, it is likely that we will replace the current 2K device for a 4K, or more likely a 7Kx9K device. The technology we developed here will be useable the day we will install more than a single device inside the focal plane. Since a 7Kx9K device covers about 10 times the area of our single 2K, Installing 4 such devices would cover basically 42% of the available field. As far as the available 2K chips, a solution would be to provide them to several active observatories around the world in order to be able to follow up or discover Near Earth Objects (Tchek republic, Russia (?), China, India, Indonesia, Australia). Since our system uses PCs and that our detection software is public domain, this would be the best possible use of these existing devices, as far as obtaining more asteroid observations. We believe we can handle the production of the required electronic controllers next year.

Financial report :

The first payment ($20,000) has been used to purchase a lot of ten grade 4 2K CCDs (CCD 442A) from Loral.

Design studies and prototype construction was paid for by the Observatoire de la Cote d'Azur Schmidt telescope.

This second payment will be used to install the next generation chip (either a 4K device supplied by DLR, or 7Kx9K which ESO (European Southern Observatory, Optical detector group - Jim Beletic) has agreed to supply to our team.